AD-A119 980 TEL-AVIV UNIV (ISRAEL) F/G 4/2

STRATOSPHERIC TURBULENCE FROM WIND SHEARS.(U)

FEB 82 N ROSENBERG F49620-81-C-0071

UNCLASSIFIED AFGL-TR-82-0284 NL

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER AFGL-TR-82-0284	2. GOVT ACCESSION NO. AD-A119980	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) STRATOSPHERIC TURBULENCE FROM WIND SHEARS		5. TYPE OF REPORT & PERIOD COVERED Final Report
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Norman Rosenberg		8. CONTRACT OR GRANT NUMBER(s) F49620-81-C-0071
9. PERFORMING ORGANIZATION NAME AND ADDRESS TEL-AVIV University Research Authority Ramat-Aviv, Israel 69978		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 62101F 668705BC
11. CONTROLLING OFFICE NAME AND ADDRESS Air Force Geophysics Laboratory Hanscom AFB, Massachusetts 01731 Monitor/Earl Good/LKD		12. REPORT DATE 28 February 1982
		13. NUMBER OF PAGES 7
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified Approved for
		15a. DECLASSIFICATION DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Stratosphere
Winds
Smoke trails

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A statistical analysis of smoke trail velocity profiles and balloon velocity profiles has been carried out to evaluate and remove their inherent noise content. The day-to-day variability in the probability of exceeding critical shear was evaluated. The corona anemometer data was compared with the much larger data-base of smoke trail data. Although the corona anemometer showed a higher probability of turbulence, it was within the variability expected from the smoke trail analysis. It is shown that the diffusion integral which

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

82 10 07 037

leads to the diffusion coefficient is very sensitive to the variability in turbulent occurence probabilities.

AFGL-TR-82-0284

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STRATOSPHERIC TURBULENCE FROM WIND SHEARS

NORMAN ROSENBERG, PRINCIPAL INVESTIGATOR

FINAL REPORT 28 FEBRUARY 1982

EUROPEAN OFFICE OF AEROSPACE RESEARCH
CONTRACT F49620-81-C-0071

ABSTRACT

A STATISTICAL ANALYSIS OF SMOKE TRAIL VELOCITY PROFILES AND BALLOON VELOCITY PROFILES HAS BEEN CARRIED OUT TO EVALUATE AND REMOVE THEIR INHERENT NOISE CONTENT. THE DAY-TO-DAY VARIABILITY IN THE PROBABILITY OF EXCEEDING CRITICAL SHEAR WAS EVALUATED. THE CORONA ANEMOMETER DATA WAS COMPARED WITH THE MUCH LARGER DATA-BASE OF SMOKE TRAIL DATA. ALTHOUGH THE CORONA ANEMOMETER SHOWED A HIGHER PROBABILITY OF TURBULENCE, IT WAS WITHIN THE VARIABILITY EXPECTED FROM THE SMOKE TRAIL ANALYSIS. IT IS SHOWN THAT THE DIFFUSION INTEGRAL WHICH LEADS TO THE DIFFUSION COEFFICIENT IS VERY SENSITITIVE TO THE VARIABILITY IN TURBULENT OCCURENCE PROBABILITIES.

STRATOSPHERIC TURBULENCE FROM WIND SHEARS

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INTRODUCTION

THE OCCURENCE OF TURBULENCE IN THE PREDOMINANTLY-LAMINAR STRATOSPHERE IS IMPORTANT IN DEFINING MODELS FOR DISPERSAL OF STRATOSPHERIC POLLUTANTS AND FOR SCATTERING OF EM WAVES SUCH AS LASER BEAMS. STATISTICAL ESTIMATES OF FREQUENCY OF OCCURRENCE OF VERTICAL SHEARS IN THE HORIZONTAL WIND SUFFICIENTLY HIGH TO CAUSE TURBULENCE HAVE BEEN MADE FROM GROUND-BASED OBSERVATION OF SMOKE TRAILS RELEASED FROM ROCKETS AND FROM BALLOON-BORNE SENSORS SUCH AS THE CORONA ANEMOMETER DEVELOPED AND FLOWN BY AFGL SCIENTISTS. THE PRESENT STUDY COMPARES RESULTS FROM THE TWO TYPES OF MEASUREMENTS WITH PARTICULAR ATTENTION TO THE APPROPRIATE STATISTICAL TREATMENT OF THE ORIGINAL DATA AND AN ESTIMATE OF THE VARIABILITY OF RESULTING INPUTS TO ATMOSPHERIC MODELS.

BACKGROUND

EARLIER REPORTS BY AFGL SCIENTISTS (REF 1) DESCRIBED PROCESSING OF 200 SMOKE TRAILS MADE BY NASA SCIENTISTS. THE CORONAN (CORONA ANEMOMETER) PROFILES OBTAINED IN AFGL EXPERIMENTS WERE DESCRIBED IN A FINAL REPORT (REF 2) UNDER OUR PREVIOUS CONTRACT. THE PRESENT STUDY REVIEWS THE DATA TREATMENT MADE IN THE EARLIER REPORTS AND REPORTS SIGNIFICANTLY-DIFFERENT CONCLUSIONS OBTAINED BY FURTHER STATISTICAL CONSIDERATIONS.

DATA SOURCES

THE DATA SOURCES ARE DESCRIBED IN REF 1 AND REF 2. THE 200 NASA SMOKE TRAILS WERE TAKEN RANDOMLY WITH RESPECT TO TIME AND SEASON. ALL WERE TAKEN DURING DAYLIGHT HOURS AND ONLY UNDER CLOUD-FREE CONDITIONS. THE AFGL BALLOON FLIGHT ANALYSED WAS TAKEN IN APRIL 1977 FROM 0500 TO 1400 LOCAL TIME. THEREFORE NO INFERENCE CAN BE MADE AS TO STATISTICS WHICH RELATE TO DISTURBED WEATHER OR DIURNAL EFFECTS.

THE NASA SMOKE PROFILES WERE AVAILABLE AS DIGITAL TAPES, REPORTED AS NORTH AND EAST VELOCITY COMPONENTS TO 0.1 M/S AT VERTICAL SPACING OF 25 METERS. NO ACCURACY ESTIMATES WERE AVAILABLE ON THE MEASUREMENTS .

THE AFGL CORONAM PROFILES WERE AVAILABLE ON DIGITAL TAPES WHICH REPORT AT 10-SECOND INTERVALS. REPORTING PRECISION IS NOT AN ACCURACY ESTIMATE.

1. GMT TIME TO 1 SECOND
2. RADAR BALLOON POSITION TO 1 METER IN NORTH, EAST, AND ALTITUDE.
3. CORONAM VELOCITY (RELATIVE TO BALLOON) TO 0.1 M/S AND DIRECTION TO 0.1 DEGREE.
4. TEMPERATURE AND PRESSURE.

THE SMOKE TRAILS WERE REPORTED BETWEEN 5 AND 20 KM AND THE CORONAM FLIGHT CONTAINED 5 UP OR DOWN 'LEGS' BETWEEN 17 AND 25 KM ALTITUDE.

THE NASA SMOKE PROFILES WERE DIRECTLY AVAILABLE AS EAST AND NORTH VELOCITY COMPONENTS. IN THE PRESENT STUDY, 75 SMOKE TRAILS WERE USED WITH THE ANALYSIS BEING MADE ON SEPARATE SEGMENTS BETWEEN 8 AND 13 KM (CONSIDERED TROPOSPHERIC) AND BETWEEN 13 AND 18 KM (CONSIDERED STRATOSPHERIC). SINCE NO TEMPERATURE DATA WAS AVAILABLE, TEMPERATURE PROFILES WERE TAKEN AS US STANDARD ATMOSPHERE VALUES. VALUES OF TEMPERATURE AND GRADIENT OF -6.5 DEG/KM IN THE TROPOSPHERE AND 0 DEG/KM IN THE STRATOSPHERE LED TO CRITICAL SHEARS FOR TURBULENCE OF 22 M/S/KM AND 45 M/S/KM RESPECTIVELY.

THE PROCESSING TO CONVERT CORONAM DATA TO EAST AND NORTH VELOCITY COMPONENTS AT 20 METER VERTICAL SPACING HAS BEEN DESCRIBED IN REF 2. TEMPERATURE PROFILES WERE AVAILABLE SO LOCAL VALUES OF CRITICAL SHEAR COULD BE COMPUTED AND THE LOCAL SHEAR RELATED TO THIS VALUE RATHER TO A STANDARD VALUE. IT SHOULD BE NOTED THAT THE LOCAL TEMPERATURE PROFILE SHOWED A DOUBLE MAXIMUM AND A RANGE OF CRITICAL SHEARS BETWEEN 35 AND 55 M/S/KM, STRADDLING THE STANDARD ATMOSPHERE VALUE OF 45 M/S/KM.

THUS LOCAL VELOCITY COMPONENTS AND LOCAL CRITICAL SHEAR VALUES WERE AVAILABLE FOR BOTH SETS OF DATA FOR FURTHER PROCESSING.

ABOUT 10000 POINTS WERE AVAILABLE FROM 75 SMOKE TRAILS AVAILABLE AT STRATOSPHERIC ALTITUDES. THE CORONAM PROFILES CONTAINED ABOUT 1000 POINTS AMONG THE 5 LEGS WHICH WERE CONSIDERED AS SEPARATE 'TRAILS'.

DATA PROCESSING

THE RELEVANT VARIABLE FOR TURBULENCE IS THE RATIO OF THE LOCAL VERTICAL SHEAR OF THE HORIZONTAL VELOCITY TO THE LOCAL CRITICAL SHEAR.

CRITICAL SHEAR IS DEFINED (REF 1) IN RECIPROCAL SECONDS AS

CRIT SHEAR = 2. * GRAV/TEMP * [DTDZ - DTDZ ADIAB]

IT IS CONVENIENT TO EXPRESS THIS IN UNITS OF MET/SEC/KM = 1000* THE ABOVE VALUE. CRITICAL SHEARS RANGE FROM 20 M/S/KM IN THE TROPOSPHERE TO 50 M/S/KM IN THE STRATOSPHERE, DEPENDING ON LOCAL TEMPERATURE GRADIENT.

SINCE THE PRIMARY DATA IS EXPRESSED AS VELOCITY, AND SHEAR IS THE DIFFERENCE BETWEEN VELOCITY VALUES, AN IMPORTANT PROBLEM IS TO RELATE TO THE INHERENT NOISE CONTENT RELATIVE TO SIGNAL. THE AVERAGE RMS DIFFERENCE BETWEEN ADJACENT POINTS SEPARATED BY 20-25 METERS WAS ABOUT 0.6 M/S. SPATIAL FREQUENCY ANALYSIS BY FOURIER TRANSFORM SHOWED A VELOCITY RMS AMPLITUDE OF 3 M/S AT THE NYQUIST FREQUENCY (CORRESPONDING TO A SPATIAL WAVELENGTH OF 40-50 METERS). A LARGE FRACTION OF THIS AMPLITUDE IS THEREFORE A RANDOM VELOCITY ERROR WHICH IS PRESENT AT ALL SPATIAL FREQUENCIES. REDUCTION OF THIS NOISE CONTENT CAN BE ATTEMPTED BY ONE OF THREE FILTERS

1. ASSUME THAT THE AVERAGE ENERGY CONTENT AT NEAR-NYQUIST FREQUENCIES IS WHITE NOISE. REMOVE THIS ESTIMATED NOISE ENERGY FROM ALL FREQUENCIES. BACK TRANSFORM TO OBTAIN A FILTERED VELOCITY PROFILE.

2. ESTABLISH THE POWER DEPENDENCE OF AMPLITUDE VS SPATIAL FREQUENCY FROM LOWER-FREQUENCY AMPLITUDES, AND RESTRICT HIGH FREQUENCY AMPLITUDES NOT TO EXCEED THE POWER LAW. RETRANSFORM TO A FILTERED VELOCITY PROFILE.

3. APPLY A SMOOTHING FUNCTION TO THE ORIGINAL VELOCITY PROFILE TO REDUCE THE HIGH-FREQUENCY CONTENT, DIRECTLY PROVIDING A FILTERED VELOCITY PROFILE.

ALL THREE FILTERS REDUCE THE VELOCITY DIFFERENCES BETWEEN ADJACENT POINTS, AND HAVE A SMALLER EFFECT ON DIFFERENCES BETWEEN POINTS WITH HIGHER SEPARATIONS. HOWEVER, ALL REDUCE THE NOMINAL RESOLUTION OF 20-25 METERS TO A POORER RESOLUTION. THE RMS DIFFERENCE BETWEEN ORIGINAL AND FILTERED PROFILES USING ANY OF THE THREE FILTERS WAS ONLY ABOUT 0.2 M/S ALTHOUGH EACH REDUCED THE HIGH FREQUENCY AMPLITUDE VALUES TEN-FOLD FROM 3 M/S TO 0.3 M/S.

A 3-POINT RUNNING AVERAGE WAS SELECTED AS THE SIMPLEST FILTER BECAUSE IT MAKES NO ASSUMPTION OF THE VALIDITY OF THE POWER-LAW DEPENDENCE OR THE WHITE-NOISE NATURE OF THE VELOCITY ERRORS. AS WILL BE SEEN BELOW FROM GRAPHS OF AMPLITUDE VS FREQUENCY, NEITHER ASSUMPTION IS VALID FOR A SINGLE TRAIL, ALTHOUGH BOTH MAY BE VALID TO THE AMPLITUDES AVERAGED OVER A NUMBER OF PROFILES.

BEFORE THIS FILTER WAS APPLIED, A STATISTICAL TEST WAS USED TO REJECT GROSS OUTLIER POINTS FROM CONSIDERATION. THE 50 PERCENTILE RMS DIFFERENCE BETWEEN ADJACENT POINTS WAS ABOUT 0.6 M/S AND THE 95 PERCENTILE WAS ABOUT 1.0 M/S. ANY POINTS WHICH SHOWED DIFFERENCES GREATER THAN 2 M/S FROM THEIR ADJACENT NEIGHBORS WERE TREATED AS GROSS ERRORS, AND IGNORED. TWO TYPES OF OUTLIERS WERE FOUND-

1. M/S= 1.0 1.1 1.3 6.2 6.3 6.5..... WHERE A 'STEP' IS PRESENT
2. M/S= 1.0 1.1 6.2 1.3 1.1... WHERE A SINGLE OUTLIER IS PRESENT.

NEITHER TYPE OF OUTLIER IS CONSIDERED POSSIBLE OVER A 20 METER SPACING AND SO BOTH TYPES WERE PRE-EDITED OUT OF THE DATA. OUTLIERS OCCURED VERY INFREQUENTLY, ABOUT 80 PCT OF THE SMOKE TRAILS SHOWED NONE, AND ONLY 3 TRAILS SHOWED MORE THAN 5 OUTLIERS IN 200 POINT SAMPLES. THESE TRAILS WERE REJECTED. IN THE CORONAM PROFILES, A TOTAL OF 20 OUTLIERS WERE FOUND IN 1000 TOTAL POINTS AND WERE EDITED OUT. FOLLOWING THIS PRE-EDITING, THE RUNNING AVERAGE WAS USED TO PRODUCE EACH FILTERED PROFILE.

FIGURE 1 SHOWS A SINGLE CORONAM VELOCITY COMPONENT PROFILE BEFORE AND AFTER FILTERING. IT ALSO SHOWS THE BALLOON VELOCITY PROFILE DERIVED FROM THE RADAR TRACK. THE SIMILARITY BETWEEN THE PROFILES IS STRIKING. NO HIGH-FREQUENCY CONTENT IS PRESENT IN THE BALLOON PROFILE, BUT IS ADDED BY THE CORONAM DATA AND IS THEN PARTIALY REMOVED BY THE FILTER.

FIGURE 2 SHOWS THE DIFFERENCE BETWEEN RAW AND FILTERED VELOCITIES FOR A SINGLE COMPONENT AND THE ADJACENT-POINT TOTAL SHEARS FOR RAW AND FILTERED PROFILES.

FIGURE 3 SHOWS FOURIER AMPLITUDES BEFORE AND AFTER FILTERING FOR (1) A SINGLE VELOCITY COMPONENT AND (2) FOR AVERAGE AMPLITUDES FOR ALL 10 CORONAM COMPONENTS (5 LEGS X 2 DIRECTIONS)

TABLE 1 AND FIGURE 4 PRESENTS THE PROBABILITY OF EXCEEDING A GIVEN SHEAR VS SHEAR AT 20-25 METER SPACING. THE TWO DATA SETS ARE THE STRATOSPHERIC PORTION OF THE SMOKE TRAILS AND THE 5 CORONAM LEGS.

TABLE 2 AND FIGURE 5 SIMILARLY PRESENTS PROBABILITY OF EXCEEDING A GIVEN RATIO OF SHEAR/CRITICAL SHEAR VS THIS RATIO.

FIGURE 6 PRESENTS PROBABILITY OF EXCEEDING GIVEN FRACTION OF CRITICAL SHEAR. THIS WAS GENERATED FOLLOWING THE PROCEDURE DESCRIBED IN REFERENCE 1. THE PROBABILITY OF EXCEEDING THE CRITICAL SHEAR WAS FOUND FOR LAYER THICKNESSES RANGING FROM THE CLOSEST SPACING (20-25 METERS) TO INCREASED ALTITUDE DIFFERENCES UP TO 400 METER LAYER THICKNESS. AS SHOWN IN FIGURE 6, PROBABILITIES OF EXCEEDING CRITICAL SHEAR AT LAYER THICKNESS OF 100 METERS RANGE FROM ABOUT 10 PCT IN UNFILTERED CORONAM TRAILS TO ABOUT 2 PERCENT IN FILTERED SMOKE PROFILES.

FIGURE 7 WAS ALSO PREPARED FOLLOWING THE PROCEDURE OF REFERENCE 1. THE INTEGRAL OF PROB(L) * L * L IS A DIFFUSION PARAMETER WITH DIMENSION M2. THIS PARAMETER, WHEN DIVIDED BY THE ESTIMATED LIFETIME OF A TURBULENT EDDY, (1000-3000 SECONDS) WAS SHOWN IN REF 1 TO BE A MEASURE OF THE EFFECTIVE DIFFUSION COEFFICIENT IN THE STRATOSPHERE. FIGURE 7 PRESENTS A PLOT OF THE CONTRIBUTION TO THE PARAMETER FROM ALL LAYER THICKNESS UP TO THICKNESS L VS LAYER THICKNESS L. AS CAN BE SEEN, THE CONTRIBUTION OF THIN LAYERS IS TRIVIAL, AND THE MAJOR CONTRIBUTION IS ONLY FROM LAYER THICKNESSES ABOVE 100 METERS. THE FINAL PARAMETER VALUES AT 400 METER SPACING ARE WITHIN A FACTOR OF 3 FOR ALL 4 DATA SETS.

DISCUSSION OF RESULTS

THE DIFFERENCES BETWEEN SMOKE AND CORONAM PROBABILITIES ARE SUBSTANTIAL, BUT NOT NECESSARILY STATISTICALLY SIGNIFICANT.

TO TEST SIGNIFICANCE, THE PROBABILITIES WERE SEPARATELY COMPUTED FOR EACH OF THE SMOKE PROFILES, WHICH PERMITTED A CALCULATION OF THE STANDARD DEVIATION AMONG THE 73 PROFILES FOR EACH PROBABILITY ESTIMATE.

TABLE 3 PRESENTS THE RESULT OF THIS CALCULATION. COLUMN 1 SHOWS LAYER THICKNESS AND COLUMN 2 THE AVERAGE NUMBER OF POINTS PER TRAIL. THE FOLLOOWING COLUMN PAIRS SHOW THE AVERAGE PROBABILITY (AMONG 73 TRAILS) OF EXCEEDING A GIVEN RATIO OF SHEAR/CRIT SHEAR AND THE STANDARD DEVIATION OF THIS AVERAGE. FOR EXAMPLE,CONSIDER THE VALUES FOR EXCEEDING A CRITICAL SHEAR OF 1. THE 25 METER LAYER THICKNESS HAS AN AVERAGE OF 3.99 PCT AND A STDV OF 3.36 PCT. THE 250 METER LAYER THICKNESS HAS AN AVERAGE 0.35 PCT WITH A STDV OF 1.12 PCT. THE DISTRIBUTION IS GENERALLY POISSON (AVG=STDV) FOR PROBABILITIES BELOW 10 PCT, AND STANDARD DEVIATIONS ARE SEVERAL TIMES LARGER THAN AVG FOR PROBABILITIES BELOW 3 PCT.

THE STANDARD DEVIATION IS A MEASURE OF DAY-TO-DAY VARIABILITY. IT SUGGESTS THAT THE CORONAM SHEARS, ALTHOUGH HIGHER THAN THE AVERAGE SMOKE PROFILES, ARE WITHIN THE EXPECTED VARIABILITY OF STRATOSPHERIC TURBULENCE.

THIS VARIABILITY SERIOUSLY AFFECTS THE ESTIMATED DIFFUSION PARAMETER. THIS PARAMETER IS DOMINATED BY LAYER THICKNESSES ABOVE 100 METERS, WHICH HAVE LOW PROBABILITIES, BUT IF THE VARIABILITY IS AS HIGH AS SHOWN, INCREASED PROBABILITIES OF THICK LAYERS WILL NOT BE INFREQUENT.

A TEST WAS MADE OF THE SENSITIVITY OF DIFFUSION PARAMETER , BY TAKING THE 0.8 AND 1.2 CRITICAL-RATIO PROBABILITY VALUES INSTEAD OF THE 1.0 RATIO VALUES. THE DIFFUSION PARAMETER INCREASED AND DECREASED BY FACTOR OF 3 BY THIS 20 PCT SHIFT IN DEFINITION OF CRITICALITY, WHICH WILL CERTAINLY OCCUR WITH THE DAY-TO-DAY VARIABILITY FOUND.

CONCLUSIONS

1. THE CONTRIBUTION TO THE DIFFUSION COEFFICIENT FROM LAYERS OF LESS THAN 100 METERS THICKNESS IS NEGLIGIBLE. EFFORTS TO INCREASE RESOLUTION TO OBTAIN 'BETTER' ESTIMATES OF DIFFUSIVITY ARE THEREFORE NOT WORTHWHILE.

2. NOISE REDUCTION BY FILTERING WITH A RUNNING AVERAGE REDUCES HIGH FREQUENCY AMPLITUDES BY A FACTOR OF 10, FROM ABOUT 3.0 M/S TO 0.3 M/S (PER UNIT FREQUENCY). THIS FILTER HAS ONLY A SMALL EFFECT ON ACTUAL VELOCITIES, RESULTING IN AN RMS CHANGE OF ONLY 0.2 M/S. THE FILTER REDUCES THE COMPUTED DIFFUSION INTEGRAL BY ABOUT 30 PCT.

3. THE DAY-TO-DAY VARIABILITY OF THE PROBABILITY OF EXCEEDI CRITICAL SHEAR IS HIGH RELATIVE TO THE LOW-PROBABILITY LARGE THICKNESSES ICH CONTROL THE DIFFUSION PARAMETER. IN FACT, THE ENTIRE FILTERING PROCES UCH SMALLER IN ITS EFFECT THAN THE DAY-TO-DAY VARIABILITY EFFECT. COMBINED WITH THE UNCERTAINTY OF TURBULENCE LIFETIME, IT WOULD APPEAR THAT ANY DIFFUSION CONSTANT ESTIMATE WILL HAVE AN UNCERTAINTY OF AN ORDER OF MAGNITUDE.

4. THE CORONAM MEASUREMENTS OF SHEAR PROBABILITY ARE HIGH WITH RESPECT TO THE AVERAGE OF THE SMOKE TRAIL VALUES, BUT ARE WITHIN THE 95 PCT CONFIDENCE LIMITS. IN OTHER WORDS, THE CORONAM RESULTS MIGHT BE EXPECTED IN 1 DAY EVERY 20.

REFERENCES

1. ROSENBERG N.W. AND E.M. BEWAN,'STARTOSPHERIC TURBULENCE AND VERTICAL EFFECTIVE DIFFUSION COEFFICIENTS', CIAP CONFERENCE (1974)

2. ROSENBERG N.W. 'STRATOSPHERIC RESIDENCE TIMES', FINAL REPORT UNDER USAF CONTRACT AF-49620-81-80-C-0071 TEL UNIVERSITY (1981)

TABLE 1. PROBABILITY OF EXCEEDING GIV SHEAR VS LAYER THICKNESS
(PROBABILITY PER 10000 POINTS)

SHEAR M/S/KM=		10	20	30	40	50	60	70	80	90	100	110
LAYER MET	PTS	PROB										
		RAW SMOKE TRAILS										
25	11472	7421	3591	1409	798	537	365	248	141	59	0	0
50	11399	7584	3230	1254	641	321	185	115	61	24	0	0
75	11326	7261	2948	1068	484	227	113	50	21	7	0	0
100	11253	7130	2745	947	378	155	62	20	8	3	0	0
125	11180	6884	2472	804	287	93	32	13	4	0	0	0
250	10815	5918	1509	362	60	10	0	0	0	0	0	0
375	10450	4887	931	131	14	0	0	0	0	0	0	0
		FILTERED SMOKE TRAILS										
25	11472	7266	2947	1057	483	227	113	50	21	7	0	0
50	11399	7188	2832	1000	428	198	91	34	10	3	0	0
75	11326	7058	2637	891	371	165	57	22	7	0	0	0
100	11253	6901	2440	819	313	103	39	12	5	0	0	0
125	11180	6733	2257	720	238	74	21	8	2	0	0	0
250	10815	5810	1406	347	55	5	0	0	0	0	0	0
375	10450	4833	901	122	11	0	0	0	0	0	0	0
		FILTERED CORONAM TRAILS										
20	955	8819	6487	3876	2052	1026	446	176	21	0	0	0
40	960	8708	6229	3635	1750	760	271	73	0	0	0	0
60	955	8607	6042	3173	1330	565	157	31	0	0	0	0
80	950	8495	5674	2642	968	368	84	21	0	0	0	0
100	945	8423	5323	2138	741	190	53	0	0	0	0	0
200	920	7902	4000	609	87	0	0	0	0	0	0	0
300	891	7251	2425	123	0	0	0	0	0	0	0	0

TABLE 2. PROBABILITY OF EXCEEDING GIVEN RATIO OF SHEAR/CRITICAL SHEAR VS LAYER THICKNESS

SHR/CRIT SHR=		.2	.4	.6	.8	1.0	1.2	1.4	1.6	1.8	2.0	2.2
LAYER MET	PTS	PROB										
		RAW SMOKE TRAILS										
25	11472	8335	4495	1765	1143	729	520	376	284	185	96	44
50	11399	8076	4363	1841	975	550	309	189	128	82	39	20
75	11326	7916	4071	1639	791	411	216	124	64	33	12	7
100	11253	7803	3338	1426	665	316	149	67	29	14	5	3
125	11180	7635	3583	1298	537	238	89	66	13	6	2	0
250	10815	5851	2452	692	200	44	6	0	0	0	0	0

250	10815	6851	2452	692	[illegible]	44	6	0	0	0	0	0
375	10450	5928	1590	371	60	6	0	0	0	0	0	0
		FILTERED SMOKE TRAILS										
25	11472	7918	4075	1539	789	411	216	124	63	32	12	7
50	11399	7659	3922	1551	738	365	195	100	46	22	7	3
75	11326	7299	3763	1426	653	321	156	63	30	12	4	0
100	11253	7658	3557	1297	542	248	96	42	15	7	1	0
125	11180	7521	3363	1187	461	195	71	23	10	3	0	0
250	10815	6776	2382	658	178	40	4	0	0	0	0	0
375	10450	5895	1544	365	57	5	0	0	0	0	0	0
		FILTERED CORONAM TRAILS										
20	965	9119	7181	5098	3109	1927	1067	560	259	93	41	0
40	960	8990	6396	4823	2927	1656	750	354	177	63	10	0
60	955	8942	6817	4576	2440	1267	545	241	105	31	0	0
80	950	8747	6526	4137	2000	832	337	189	53	11	0	0
100	945	8751	6370	3577	1714	614	296	138	11	0	0	0
200	920	8196	5130	2098	533	163	22	0	0	0	0	0
300	895	7754	3855	1050	156	22	0	0	0	0	0	0

TABLE 3 PROBABILITY OF EXCEEDING GIVEN RATIO OF SHEAR/CRIT SHEAR FOR 73 FILTERED SMOKE PROFILES. COLUMN PAIRS ARE AMONG-TRAIL AVERAGES AND STANDARD DEVIATIONS EXPRESSED AS PROBABILITY PER 10000.

	SH/SHCR=	.2		.4		.6		.8		1.0		1.2		1.4		1.6		1.8	
SPAC	PTS	AVG	SD																
25	157	7889	1021	4019	1252	1601	746	765	487	399	336	211	219	119	147	61	91	32	68
50	156	7821	1039	3869	1285	1513	751	712	502	355	315	188	212	78	139	44	91	20	53
75	155	7772	1043	3707	1296	1374	734	632	484	309	317	150	197	60	105	29	73	10	38
100	154	7627	1107	3500	1320	1258	761	520	457	236	232	93	148	41	89	14	48	5	25
125	153	7494	1159	3313	1299	1152	770	444	444	187	261	68	130	23	67	8	32	2	13
250	148	6733	1510	2311	1271	637	698	174	300	35	112	[illegible]	19	0	0	0	0	0	0
375	143	5849	1754	1482	1179	362	349	54	163	9	23	0	0	0	0	0	0	0	0

FIGURE 1. CORONAM LEG 1 17-25 KM ALTITUDE

CURVE 1 BALLOON VELOCITY (FROM RADAR)
2 CORONAM RELATIVE VELOCITY + BALLOON VEL DIFFERENCE
3 FILTERED CORONAM VELOCITY

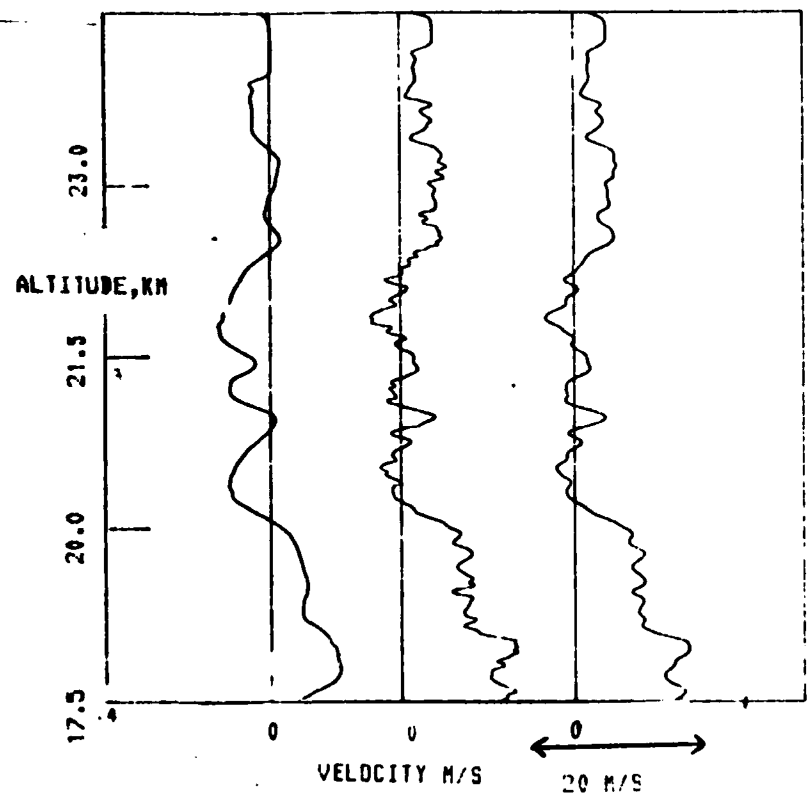


FIGURE 2 SAME TRAIL AS FIGURE 1

CURVE 1 DIFFERENCE IN VELOCITY BETWEEN ORIGINAL AND FILTERED PROFILES
2 VEL DIFF BETWEEN ADJACENT POINTS IN RAW PROFILE
3 VEL DIFF BETWEEN ADJACENT POINTS IN FILTERED PROFILE

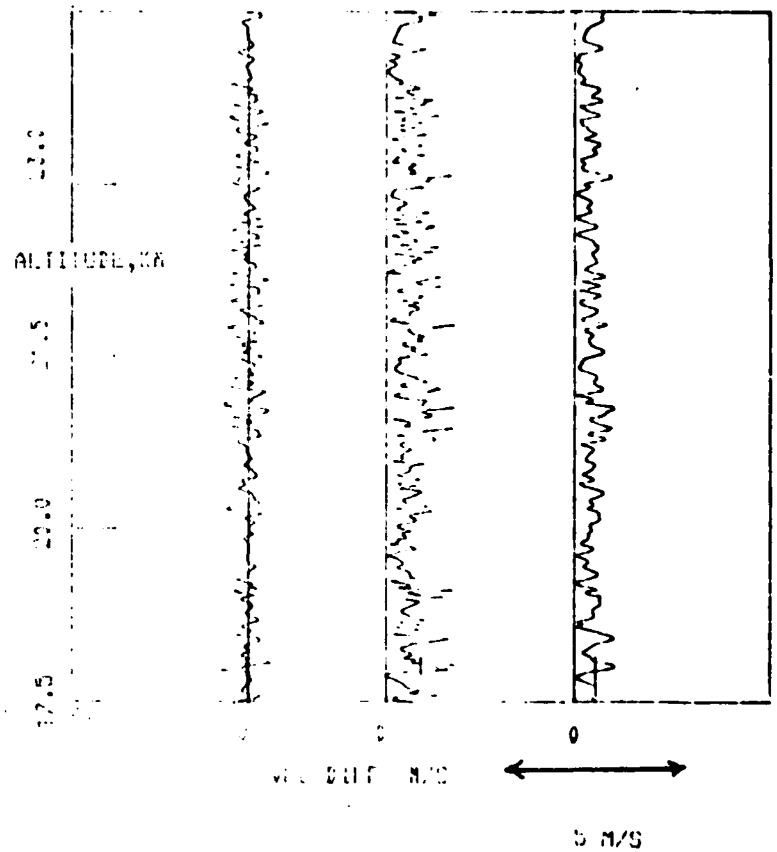


FIGURE 3 CORONAM AMPLITUDE VS SPATIAL FREQUENCY (LOG SCALES)

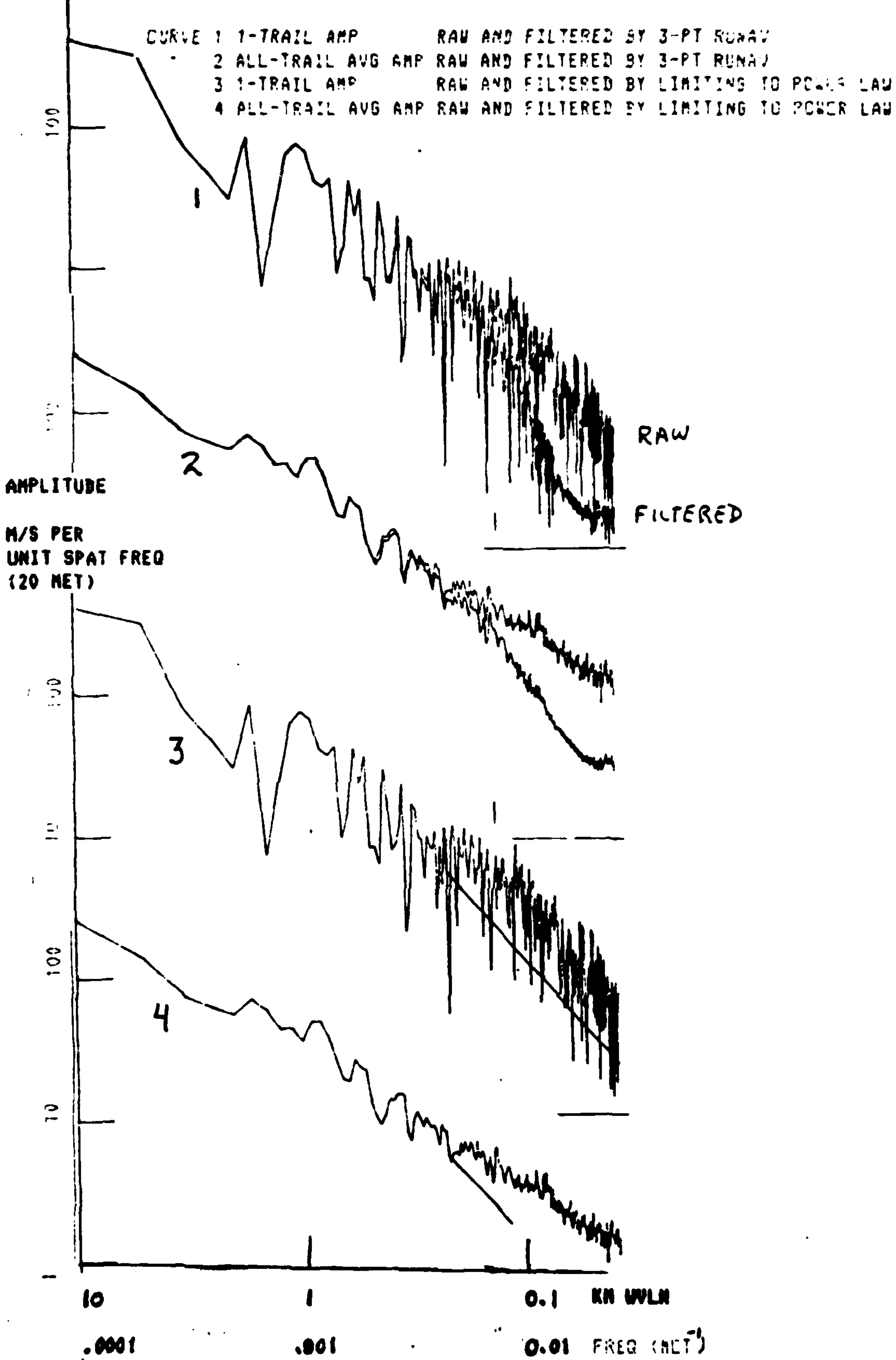


FIGURE 4 PROBABILITY OF EXCEEDING GIVEN SHEAR IN 20-25 METER LAYER THICKNESS

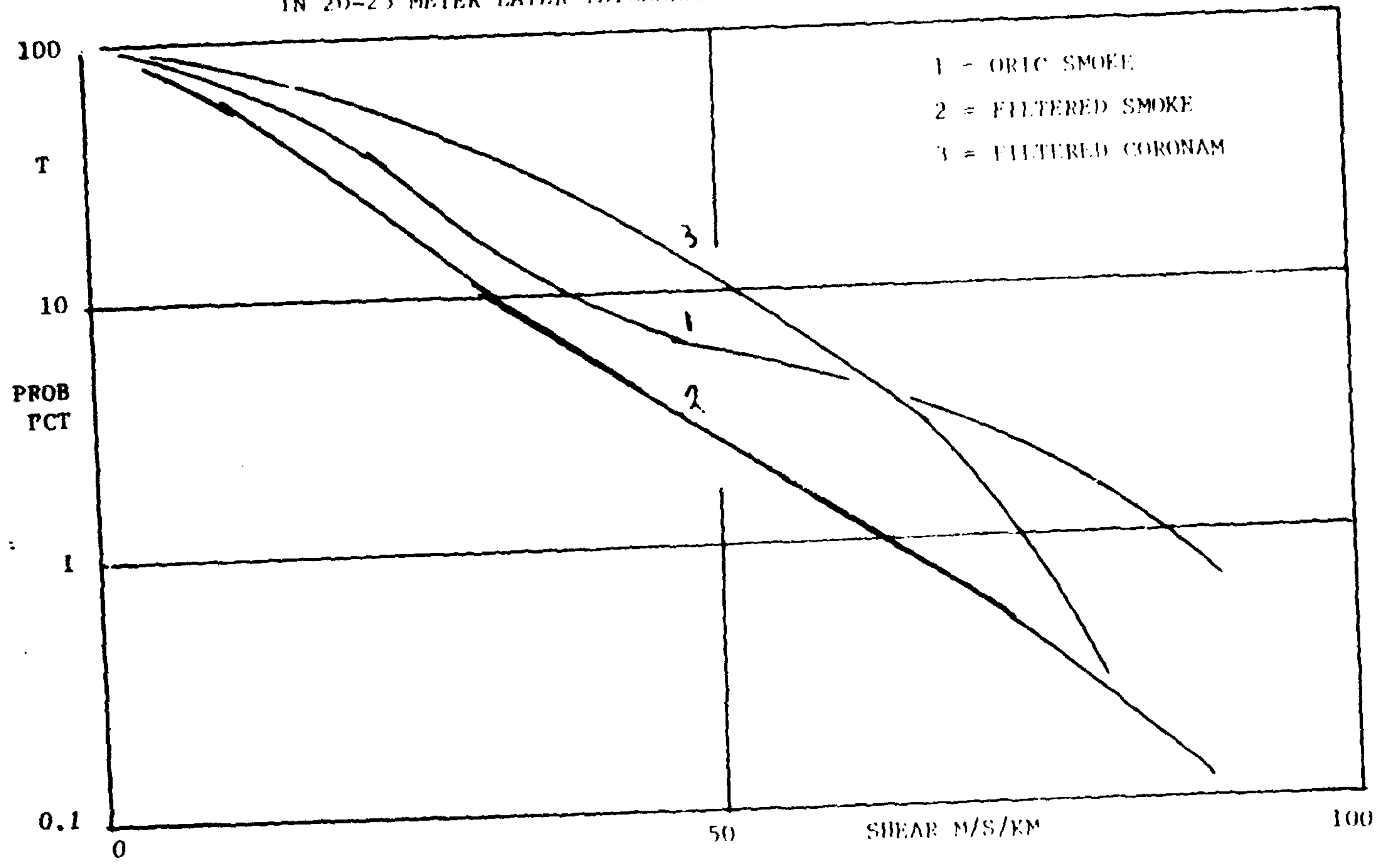


FIGURE 5 PROBABILITY OF EXCEEDING SHEAR/CRITICAL SHEAR

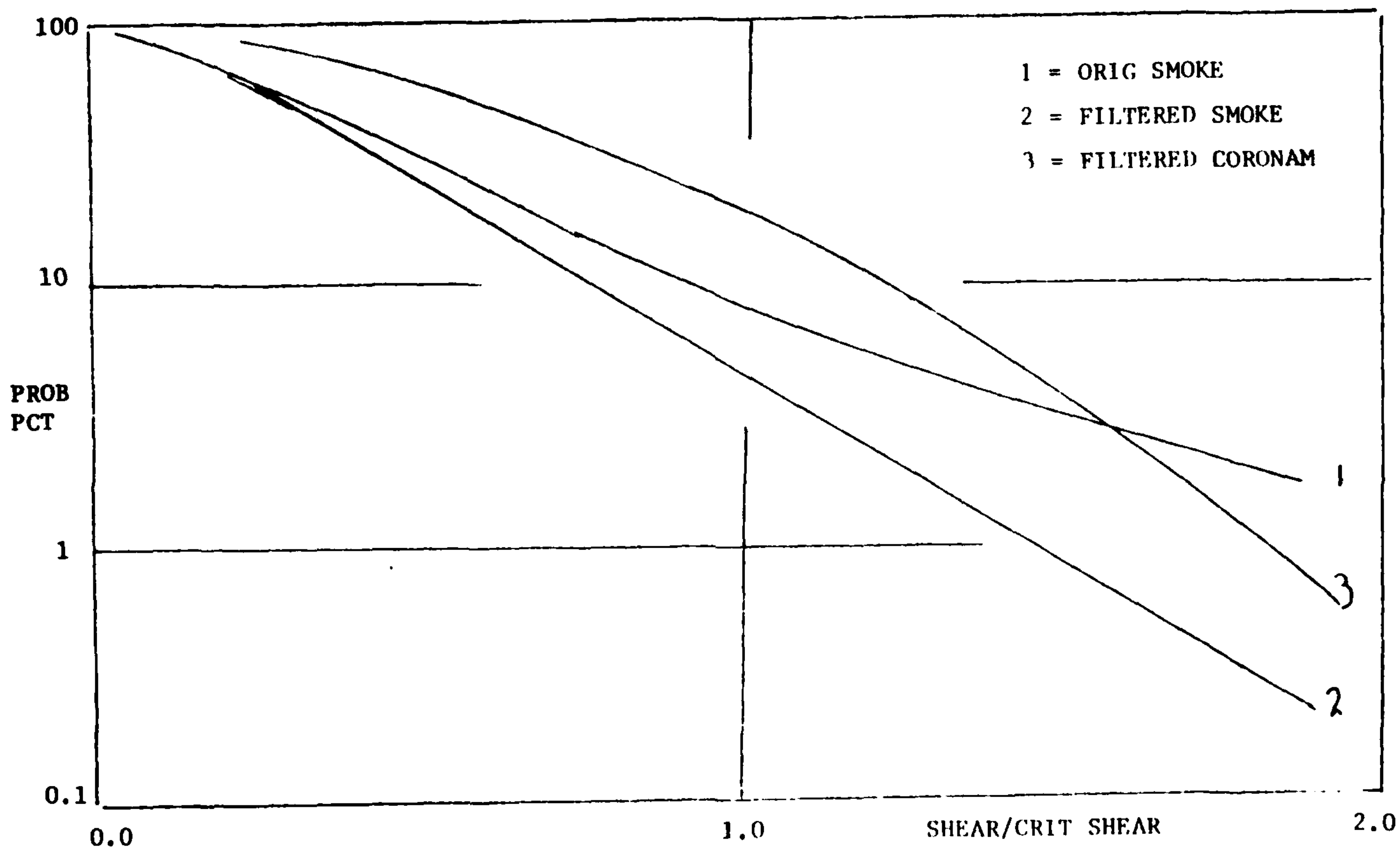


FIGURE 6 PROBABILITY OF EXCEEDING RATIO SHR/CRIT = 1 VS LAYER THICKNESS

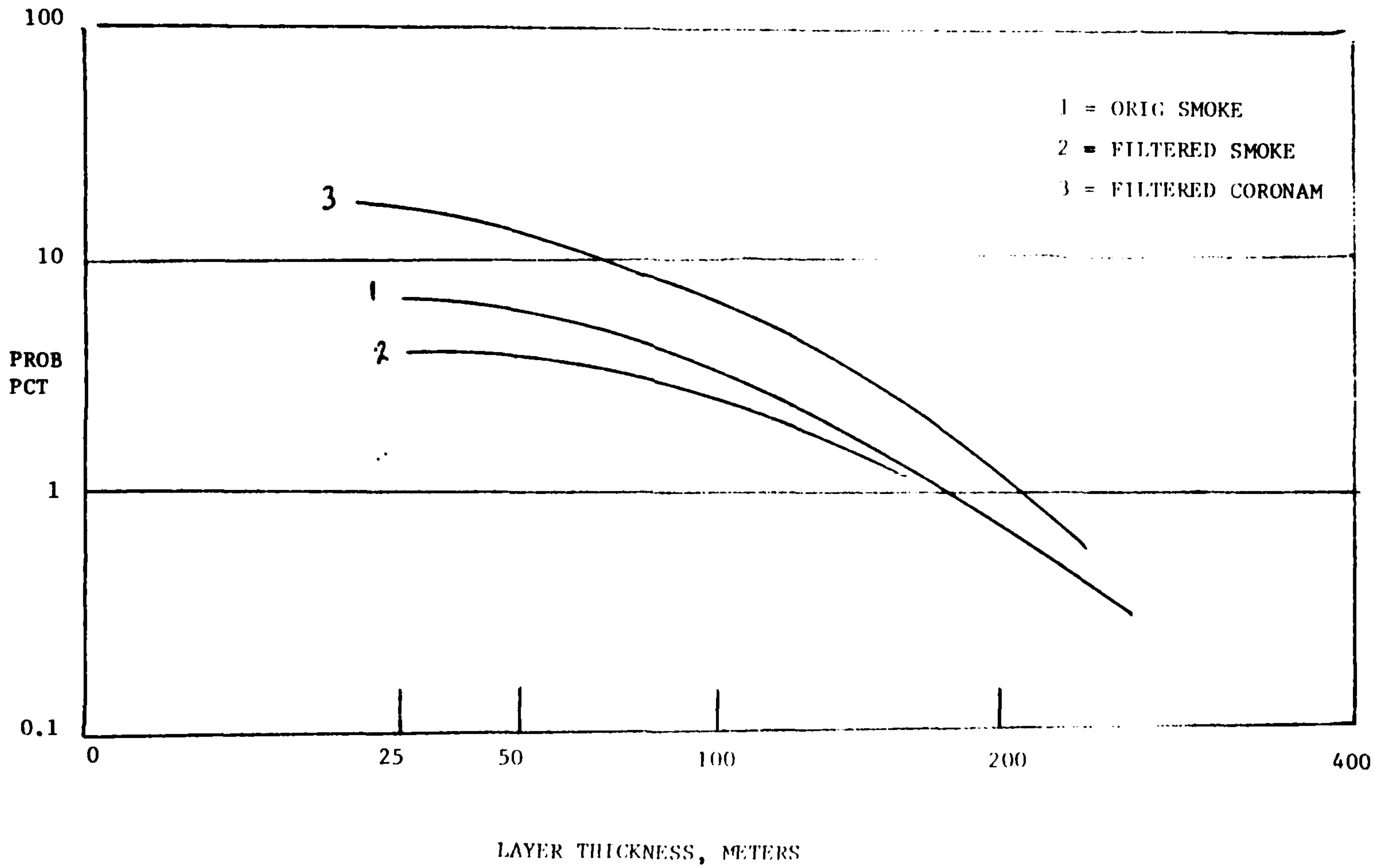
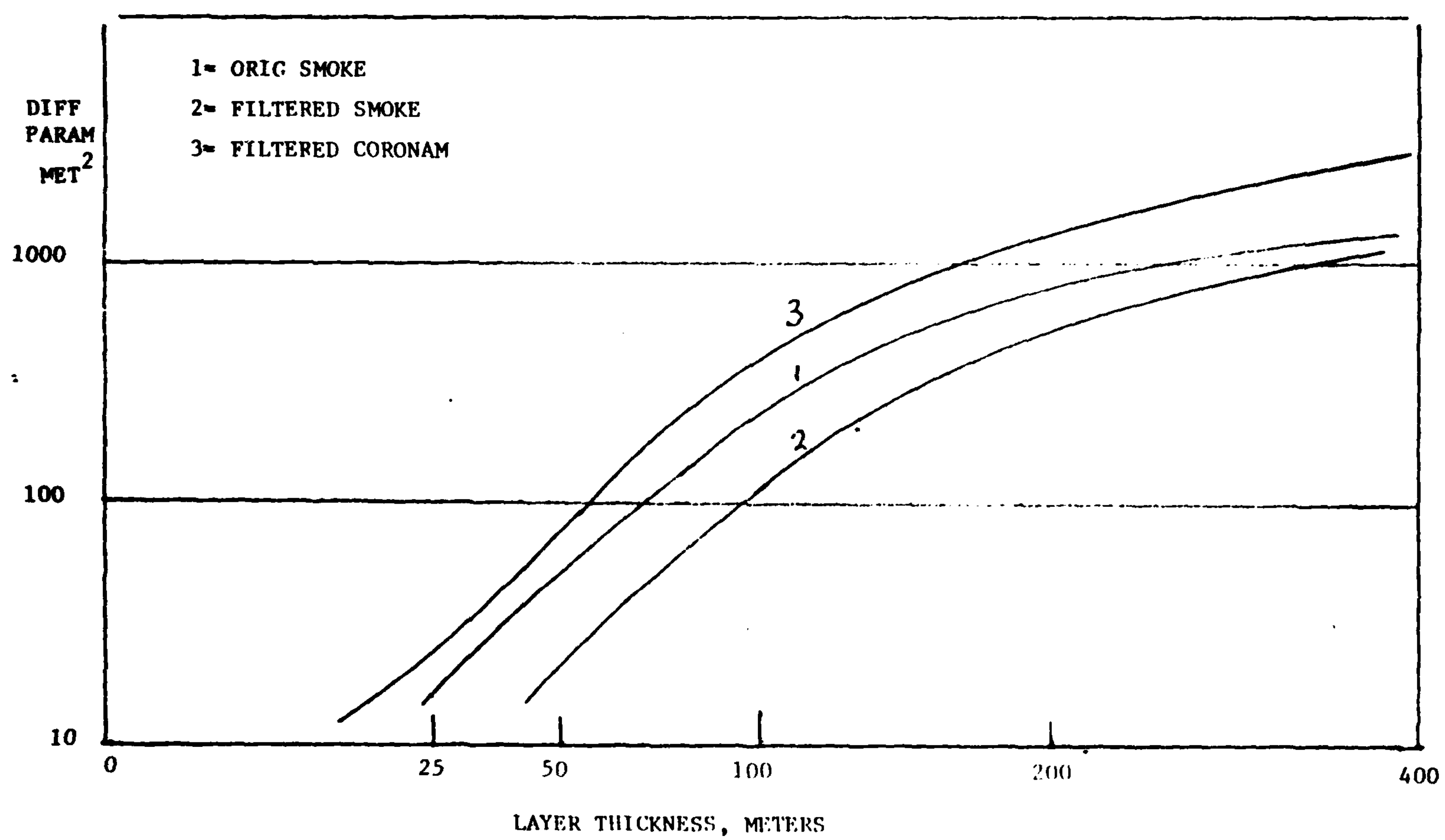


FIGURE 7 DIFFUSION PARAMETER VS LAYER THICKNESS L $\int_{o}^{L} P(L).L^{2}dL$



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DATE
FILMED

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